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A SKETCH OF THE CHIEF GEOLOGICAL ZONES AND THEIR MOLLUSCA.

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The subject of my Address has been chosen with a view of placing before the Society one of the many important applications of the fossil Mollusca. In the brief history that will be submitted it will be observed that molluscan species have been frequently selected as index-fossils for the determination of certain subdivisions of the sedimentary rocks which are known as geological zones. To the ordinary student of modern Mollusca fossil shells present few features of interest, probably on account of their frequently imperfect condition or because an acquaintance with geological questions is indispensable before attempting their study or determination. The palæoconchologist, it is only too true, has often to be content with fragmentary and mineralized specimens and sometimes casts or even impressions, from a study of which he is expected to solve problems relating to the geological age of the shell or assemblage of shells, as well as to consider the many structural characters which may come under observation. Several writers have insisted upon a knowledge of the fossil Mollusca as a powerful aid in comprehending the history of existing forms, and it is pleasant in this connection to know that our former President, Mr. B. B. Woodward,[1] in his Address before the Society on "Malacology *versus* Palæoconchology", emphasized the importance of the subject as bearing upon the phylogenetic relationships of modern shells. No information on geological zones would be complete without a reference to the early work of William Smith, who was styled the "Father of English Geology". Smith[2] was the first geologist of this country to properly grasp the fact that stratified deposits followed a regular sequential arrangement, and that each layer had its distinct fossils which represented the fauna or flora at the time of deposition, and from such studies he was able to assert that strata were determinable by the organic remains which they contained.

Smith's work in this direction was an important advance on our previous knowledge, and greatly influenced palæontological studies in this country. It came to be the basis of the complicated zoning system of the rocks which at the present day has developed to almost a science in itself, with far-reaching results. The varied and abundant forms of Mollusca found in the different strata have made them valuable indices of age, many of the more characteristic having been adopted as names for certain of the geological zones now recognized.

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[1] Proc. Malac. Soc. London, vol. viii, p. 66, 1908.
[2] *Strata Identified by Organized Fossils*, 1816.

It is necessary to understand exactly the meaning of the term 'zone' in its geological application, because some authors have regarded it as a group of "organic remains of which one abundant and characteristic form is chosen as an index",[1] in which sense the zone would be of purely zoological value; whereas it would appear from Dr. Marr's[2] interpretation that this term should be regarded as a geological factor, and might better be explained thus: "Zones are belts of strata, each of which is characterized by an assemblage of organic remains of which one abundant and characteristic form is chosen as an index."

Mr. Jukes-Browne,[3] fully approving of Dr. Marr's views, agreed also with the general opinion that the zonal methods employed in the classification of the sedimentary rocks were merely a development of William Smith's original idea that formations could be determined by their organic contents — "Just as one stage is identified and distinguished from others by the assemblage of fossils it contains, so in its turn is the zone identified by its fossils."

Zones are frequently of wide distribution and vary much in thickness. According to Mr. H. B. Woodward[4] "the zone of *Ammonites annulatus* in Yorkshire is some 30 feet thick, although represented in other parts of England by the thin layer known in Northamptonshire as the 'Transition Bed', which is very fossiliferous, but only a few inches thick, such a phenomenon forming a good illustration of the manner in which a bed may become attenuated in its range over distant geographical areas".

Geological zoning has mostly been attempted among the marine formations of Palæozoic and Mesozoic age, whereas the Cainozoic rocks, although often analytically classified into beds, have not yet received the same treatment of zonal classification as exemplified in the older stratified deposits.

For reference, in connection with the zones which will be now briefly described, a chart of the sedimentary formations has been introduced, which it is hoped may be of assistance to the student in comprehending the positions of the various geological horizons that will be alluded to.

Palæozoic Zones.

In the older Palæozoic rocks where molluscan remains are often obscure and sometimes difficult to determine, the index-fossils of the zones have been selected from among the more prolific organisms of other groups, such as the Trilobites (*Olenellus*, etc.), the Graptolites, or the Brachiopoda. Among Continental palæontologists, Barrande[5] may be quoted as having published important results in connection with his examination of the Mollusca and other invertebrates found in the Lower Palæozoic deposits of Bohemia, which, although not quite

[1] H. B. Woodward, "On Geological Zones": Proc. Geol. Assoc., vol. xii, p. 298, 1892.
[2] *The Principles of Stratigraphical Geology*, 1898, p. 68.
[3] Geological Magazine, 1899, pp. 216–19.
[4] "On Geological Zones": Proc. Geol. Assoc., vol. xii, 1892.
[5] *Système Silurien du Centre de la Bohême*, 1865–81 (Cephalopoda, Pteropoda, and Pelecypoda).

An Abridged Table of the Stratified Rocks.

Cainozoic or Tertiary.	**Holocene**	*Alluvium*, *Sand*, *Peat Beds*, *etc.*
	Post-Pliocene	*Glacial*, *Forest Bed*, *Wexford Gravel*, *etc.*
	Pliocene	*Sicilian*, *Astian*, *Plaisancian* — British Crags, Lenham Beds, etc.
	Miocene	*Pontian*, *Sarmatian*, *Tortonian*, *Helvetian*, *Burdigalian*, *Aquitanian* — Unrepresented in Britain.
	Oligocene	*Stampian* or *Rupelian* — Hempstead Beds (Isle of Wight).
		Tongrian — Bembridge, Osborne, Headon Beds, Brockenhurst, etc.
		Priabonian — Not present in Britain.
	Eocene	*Bartonian* — Barton Beds.
		Lutetian — Bracklesham Beds.
		Londinian — London Clay.
		Thanetian — Thanet Sands.
		Montian — Not present in Britain.
Mesozoic or Secondary.	**Cretaceous**	*Danian*, *Senonian*, *Turonian* — Various members of the 'White' Chalk formation; the Danian is not present in Britain.
		Cenomanian — Greensand, Chalk Marl, etc.
		Albian — Gault, Red Chalk, Blackdown, etc.
		Aptian — Hythe and Sandgate Beds, etc.
		Barremian — Atherfield Clay, etc.
		Neocomian — Speeton Clay, Tealby Beds, etc.
		Wealden — Hastings, Horsham, etc.
	Jurassic	*Purbeckian* — Dorset (Swanage), Sussex (Brightling).
		Portlandian — Portland, Tisbury, etc.
		Kimeridgian — Kimeridge Clay.
		Corallian — Coralline Oolite, etc.
		Oxfordian — Oxford Clay.
		Callovian — Kelloways Rock.
		Bathonian — Cornbrash, Great Oolite, etc.
		Bajocian — Inferior Oolite, etc.
		Aalenian — Midford Sands, Northampton Sands, etc.
		Toarcian, *Pliensbachian*, *Sinemurian* — Liassic Series.
	Triassic	*Rhætian* — *Avicula contorta* zone.
		Keuperian — Warwickshire, etc.
		Conchylian — Not present in Britain.
Palæozoic or Primary.	**Permian**	*Thuringian*, *Penjabian*, *Artinskian* — Magnesian Limestone Series, Durham, etc.
	Carboniferous	*Ouralian* — Coal-measures.
		Moscovian — Millstone Grit and Yoredale Beds.
		Dinantian (*Culm*) — Mountain Limestone, etc.
	Devonian	*Condrusian*, *Eifelian*, *Coblentzian* — Old Red Sandstone Beds of United Kingdom.
	Silurian	*Ludlovian* — Ludlow Series.
		Wenlockian — Wenlock and Woolhope.
		Valentian — Llandovery Beds.
	Ordovician	*Caradocian* — Bala or Caradoc Beds.
		Llandeilian — Llandeilo Flags.
		Arenigian — Arenig, Skiddaw, Tremadoc Series.
	Cambrian	*Olenidian* — Lingula Flags.
		Paradoxidian — Menevian Beds.
		Olenellian — Harlech and Longmynd Group.

on the lines of modern zoning work with its index-fossils, was nevertheless very detailed and analytical in its scope.[1]

Barrande recognized that shells and other invertebrates were associated in 'colonies' or provinces, and that they could be traced over distant localities, representing, therefore, separate faunas of different marine areas. He was of opinion that there were "three distinct faunas in the Bohemian strata" below the Devonian. The first or oldest fauna he called the 'Primordial zone' or Étage C, the equivalent of the Cambrian; the second fauna was grouped as Étage D, and represented the Lower Silurian of Murchison; the third fauna included Étages E, F, G, or the Upper Silurian, as also defined by Murchison.

It is not until Carboniferous times are reached that molluscan organisms, especially in this country, appear to take a more prominent part in the history of stratification. In connection with the assemblage of shells, rather than with actual zonal forms, Dr. Wheelton Hind,[2] writing "On the Subdivisions of the Carboniferous Series in Great Britain", mentioned that the various Mollusca of the Yoredale rocks of Yorkshire, as originally described by John Phillips, were equivalent to those characterizing the Carboniferous Limestone of Derbyshire. In his subdivisions of the Carboniferous System Dr. Hind recognized three distinct faunas, which were tabulated in descending order as—

(1) The Coal-measure fauna, rich in fish-remains and the freshwater Pelecypod genera *Carbonicola*, *Anthracomya*, and *Naiadites*.

(2) The Lower Coal-measures and Grit fauna, the Gannister and Grit Series; largely marine, but littoral, containing *Aviculopecten* and *Posidoniella* as Pelecypod genera, *Goniatites*, *Orthoceras*, and *Nautilus* as Cephalopoda, and some peculiar Gastropoda.

(3) The Limestone fauna, essentially marine, rich in Corals, Brachiopods, and Mollusca. Many genera of Pelecypoda, such as *Pecten*, *Avicula*, *Edmondia*, *Sanguinolites*, etc., as well as Gastropoda, including *Euomphalus*, Pleurotomaroid genera, *Murchisonia*, *Loxonema*, etc., and Cephalopoda.

During the following year the same author[3] proposed a slightly more analytical scheme for subdividing the Carboniferous Series of England, Scotland, and Ireland, based upon certain species of the Pelecypoda, Cephalopoda, and Brachiopoda, which he termed zones, and which may be thus enumerated:—

Zones of—	
(1) *Anthracomya Phillipsi* . . .	Upper Coal-measures.
(2) *Naiadites modiolaris* and *Anthracomya modiolaris*.	Middle Coal-measures.
(3) *Aviculopecten papyraceus*, *Gastrioceras carbonarium*, *Posidoniella lævis* and *minor*.	Lower Coal-measures: Ganister Series, Millstone Grit, and Shales below Millstone Grit.
(4) *Productus giganteus* and *P. cora* .	Carboniferous Limestone Series.
(5) *Modiola Macadami* . . .	Lower Limestone Shales, Calciferous Sandstone Series, etc.

[1] It should be mentioned that the molluscan names, as well as all horizonal terms employed in this account of the geological zones, are those of the different authors who have written upon this subject, no attempt having been made by the present writer to place them on a more up-to-date basis.

[2] Geological Magazine, 1897, p. 205. [3] Ibid., 1898, p. 61.

Further valuable work has been accomplished within the last few years towards more completely zoning the same series of rocks in Great Britain, but the index-fossils in connection therewith have been chosen, not from among the Mollusca, but mostly from the Brachiopoda and Corals, so that its consideration does not come within the scope of the present account.

Mesozoic Zones.

The Mesozoic rocks have received a large share of study in connection with their classification into zones.

First of all there is the zone of *Avicula contorta*, established by Dr. Wright in 1860,[1] characterizing the Rhætic beds, which he regarded as the equivalent of the 'Kossener Schichten' and the Upper St. Cassian strata of the Tyrol and other European districts, and consequently belonging either to the topmost series of the Triassic deposits or the basal beds of the Liassic system. The Pelecypod which gives its name to this zone was originally described by Captain Portlock[2] from Ireland, but the best section of the Rhætic formation is undoubtedly to be seen in the cliffs from Penarth Head to Lavernoch Point, to the south of Cardiff. It is here that the *Avicula contorta* occurs in greatest abundance, and usually in a crushed condition, making up the black shaly beds and shelly limestones of this formation, accompanied by numerous examples of *Cardium rhæticum*, in a similar state of preservation.

According to Mr. H. B. Woodward,[3] the Rhætic beds are situated between the Red Marls of the Keuper Series and the Lower Lias, and extend across England from near Redear in Yorkshire to near Lyme Regis and Axmouth on the coast of Devonshire.

For most exhaustive accounts of the *Avicula contorta* zone we are indebted to the writings of Thomas Wright[4] and Charles Moore.[5]

In much more modern years the Trias rocks of European and Asiatic countries (India, etc.) have been carefully zoned according to the Ammonites by such authorities as Mojsisovics, Suess, Diener, and Waagen.[6]

The Liassic rocks which follow the Rhætic deposits have been specially adapted for zoning on account of the numerous Ammonites, which, commencing in the lowest beds, continue throughout the whole of the Mesozoic system. Some of the earliest remarks on this subject were made by Louis Hunton[7] in 1838, who, studying Lias sections near Whitby, observed that "of all organic remains the Ammonoids afford the most beautiful illustration of the subdivision of strata, for they appear to have been the least able, of all the Lias genera, to conform to a change of external circumstances". He also noted the

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[1] Quart. Journ. Geol. Soc., vol. xvi, p. 374, 1860.
[2] *Report Geology Londonderry*, etc., 1843, p. 126.
[3] *The Geology of England and Wales*, 2nd ed., pp. 245, 246, 1887.
[4] Quart. Journ. Geol. Soc., vol. xvi, p. 374, 1860.
[5] Ibid., vol. xvii, p. 483, 1861.
[6] Sitz. Akad. Wiss. Wien, 1895, vol. cix.
[7] Trans. Geol. Soc. London, ser. II, vol. v, p. 215, 1838.

limited vertical range of the species of Ammonites and other Testacea. Similar views were held by Mr. C. Williamson[1] and published the same year, he recognizing that subdivisions of the Lias were characterized by certain species of *Ammonites*, *Belemnites*, and other Mollusca.

A few years later similar zonal work was accomplished on the Continent by Quenstedt,[2] with regard more especially to the German Jurassic rocks, and he was followed by Oppel[3] in the same direction, his remarkable investigations extending over the Jurassic formations of England, France, and South-Western Germany. Oppel recognized the importance of the guide or index-fossil for the accurate determination of the strata without reference to lithological characters, and on this basis established a number of zones mainly on certain species of the Ammonites, and he determined the zone of *Ammonites raricostatus* as the highest or latest division of the Lower Lias rocks. In his account Oppel gives detailed particulars of the typical Mollusca and other invertebrates characterizing each zone, but these are not reproduced in the present notice.

Oppel's Lias zones were as follows:—

Upper Lias or Toarcien	Zone of *Ammonites Jurensis*.
	,, *Posidonomya Bronni*.

The chief localities for the Upper Lias zones are given as Whitby, Frocester, Ilminster, France (Caen, etc.), Germany (Boll, etc.).

Middle Lias or Liasien	Zone of *Ammonites spinatus*.
	,, *A. margaritatus*.
	,, *A. Davœi*.
	,, *A. ibex*.
	,, *A. Jamesoni*.

The chief of the Middle Lias localities are given as coast of Yorkshire, Gloucestershire, Charmouth (Dorset), France (Côte d'Or), Germany.

Lower Lias or Sinemurien	Zone of *Ammonites raricostatus*.
	,, *A. oxynotus*.
	,, *A. obtusus*.
	,, *A. tubercularatus*.
	,, *A. Bucklandi*.
	,, *A. angulatus*.
	,, *A. planorbis*.

The leading localities given for the Lower Lias zones are Dorset (Lyme Regis), Somerset (Watchet), Yorkshire (Robin Hood's Bay), Gloucestershire, France (Yonne, etc.), Germany (Würtemberg).

Keuper . . Bone-bed.

Dr. Wright[4] published in 1858 an interesting account of some Liassic fossils, mostly Mollusca, from the Scottish islands of Pabba,

[1] Trans. Geol. Soc. London, ser. II, vol. v, p. 223, 1838.
[2] *Das Flözgebirge Württembergs*, 1843, and *Der Jura*, 1858.
[3] *Die Juraformation Englands, Frankreichs, und des südwestlichen Deutschlands*, 1856–8.
[4] Quart. Journ. Geol. Soc., vol. xiv, p. 24, 1858.

Scalpa, and Skye, which had been collected by Sir Archibald Geikie. From an examination of these specimens he found it possible to partially zone the beds of that region, a result more or less accomplished from a comparison with the faunas characterizing the Liassic subdivisions of Swabia (Quenstedt), Würtemberg (Oppel), France (Orbigny), and Gloucestershire (Wright).

Lower Lias beds were recognized in Skye, not by Ammonite remains, but by the presence of *Cardinia concinna*, J. Sowerby, a species characterizing fairly low deposits of the Lower Lias in Würtemberg and France; *Ostrea arietis*, Quenstedt, was also determined from the same locality and beds.

The better preserved shells, however, were obtained from the 'Pabba Shales' and regarded as of Middle Lias age—

Cephalopoda . .	*Belemnites elongatus, paxillosus, breviformis; Ammonites Jamesoni, brevispina, Davœi.*
Gastropoda . . .	*Trochus imbricatus.*
Pelecypoda . . .	*Gryphœa cymbium, obliquata; Gervillia Macculloch; Plicatula spinosa; Pecten æquivalvis; Inoceramus ventricosus; Limea acuticosta; Lima Hermanni, gigantea; Pinna folium; Mytilus cuneatus; Unicardium cardioides; Pleuromya unioides, Scottica; Pholadomya ambigua.*

In 1860 Dr. Thomas Wright[1] published his scheme for the subdivisions of the Lower Lias as exhibited in the South of England. He selected six species of Ammonites as his guide-fossils, and adopted Oppel's view in considering *Ammonites raricostatus* as forming the topmost zone of the series; in descending order these zones were as follows:—

Zone of *Ammonites raricostatus*.
,, *A. oxynotus*.
,, *A. obtusus*.
,, *A. Turneri*.
,, *A. Bucklandi*.
,, *A. planorbis*.

During 1875 Professor Judd[2] published his memoir on the "Geology of Rutland", in which he classified into zones the various beds of the Lias of that district, founded on species of Ammonites. He took occasion to warn the student against placing too great a reliance on the zonal fossils, because, as deposits were distributed over great areas, certain gradual changes may have taken place in their faunas, so much so in fact that the index-species observed in one district may be even missing from the same stratum when occurring in another locality. Professor Judd concluded from this that zonal species are not uniformly the same over a great area, although the general assemblage of organisms presents a similar facies. This author's divisions of the

[1] Quart. Journ. Geol. Soc., vol. xvi, p. 374, 1860.
[2] Mem. Geol. Surv. England and Wales, 1875, p. 89.

Lias differed slightly from that of Oppel and Wright's schemes, inasmuch as he regarded *Ammonites capricornus* as the uppermost zone of the Lower Lias instead of *raricostatus*, thus following Quenstedt's views in connexion with the Jurassic subdivisions of Germany. Professor Judd's arrangement of the Liassic zones is, however, the one adopted by the Geological Survey of this country. Its zones, in descending order, are as follows:—

Upper Lias . .	*Ammonites Jurensis, communis.*
Middle Lias .	*A. spinatus, margaritatus.*
Lower Lias . .	*A. capricornus*(?), *ibex*(?), *Jamesoni, armatus, oxynotus, obtusus, semicostatus, Bucklandi, angulatus, planorbis.*

It should be mentioned here that Waagen had published a preliminary paper in 1869[1] dealing with the Ammonites and their nomenclature, in which it was suggested that the term Ammonites should no longer be applicable as a generic name, although it might be used to designate a group. He therefore divided these Cephalopods into genera and sub-genera, according to the length of the chamber occupied by the animal, the form of the mouth, the characters of the aptychus when present, and the sculpture, the lobes being regarded as only of secondary importance. The names thus established were: *Ægoceras*, *Arietites*, *Amaltheus*, *Harpoceras*, *Oppelia*, *Œkotraustes*, *Stephanoceras*, *Perisphinctes*, and *Cosmoceras*.

Messrs. Tate & Blake, in their history of "The Yorkshire Lias" of 1876, recognized the following Liassic zones in that county, founded upon Ammonite species:—

Upper Lias	Zone of *Ammonites Jurensis.*
	,, *A. communis.*
	,, *A. serpentinus.*
Middle Lias	,, *A. annulatus.*
	,, *A. spinatus.*
	,, *A. margaritatus.*
	,, *A. capricornus.*
	,, *A. Jamesoni.*
Lower Lias	,, *A. oxynotus.*
	,, *A. Bucklandi.*
	,, *A. angulatus.*
	,, *A. planorbis.*
Rhætic.	*Avicula contorta* Beds.

These authors adopted the new generic nomenclature of Waagen and others for the Ammonites in the descriptive part of their work, but retained the term *Ammonites* in the generic sense for stratigraphical purposes.

Some years later Dr. Wright[2] published his great Monograph of the Lias Ammonites of the British Islands, in which the Lias deposits of this country were considered as corresponding to a large extent with

[1] Benecke's Paläontologische Beiträge, vol. ii, pt. ii, 1869; a fuller treatment of the same subject being published by Waagen the year following in the Palæontographica, vol. xvii, pp. 185–220, 1870.

[2] Palæontographical Society, 1878–86.

the Würtemberg Series of Germany. In this account the author gave a complete list of Lias zones, that is, including those forming the Lower, Middle, and Upper divisions of the formation, because hitherto he had only zoned the lower beds. Another innovation on this occasion was the introduction and adoption of the modern nomenclature for the Ammonites as stratigraphical index-fossils, as proposed by W. Waagen and emended by such authors as Mojsisovics, Neumayr, etc. Wright's zones were as follows:—

Upper Lias . .	*Lytoceras Jurense*, *Stephanoceras commune*.
Middle Lias. .	*Amaltheus spinatus*, *A. margaritatus*, *Œgoceras Henleyi*, *Amaltheus ibex*, *Œgoceras Jamesoni*.
Lower Lias . .	*Arietites raricostatus*, *Amaltheus oxynotus*, *Arietites obtusus*, *A. Turneri*, *A. Bucklandi*, *Œgoceras angulatum*, *Œ. planorbis*.
Rhætic . . .	*Avicula contorta*.

The Inferior Oolite and later Jurassic rocks, which succeed the Liassic Series, have been subjected to much study by palæontologists for many years. Dr. Oppel,[1] however, was among the first to submit them to a systematic classification of zonal subdivisions, and, as in the case of the Lias, it was mostly on the basis of Ammonite characters, although other mollusca were adopted for this purpose, as well as Brachiopods, Echinoderms, etc. In descending order these zones may be enumerated as—

Portland and Kimeridge Group, or Kimeridgien	Zone of *Trigonia gibbosa*.
	,, *Pterocera oceani*.
	,, *Astarte supracorallina*.
	,, *Diceras arietina*.

The localities given for the Portlandian and Kimeridgian Group included the Island of Portland, Purbeck, Kimeridge, and Osmington (Dorset); Tisbury, Swindon, and Wooton Basset (Wilts); Shotover (Oxfordshire); Aylesbury (Bucks); Hunstanton (Norfolk); Filey Bay (Yorkshire). European localities were referred to places in South-West Germany, the Swiss Jura, and France.

Oxford Group or Oxfordien	Zone of *Cidaris florigemma*.
	,, *Ammonites biarmatus*.

The localities for the Oxfordien were: near Weymouth (Dorset); Wooton Basset, Chippenham, and Calne (Wilts); Malton and Scarborough (Yorkshire). European: South-West Germany, Swiss Jura, France.

Kelloway Group or Callovien	Zone of *Ammonites athleta*.
	,, *A. anceps*.
	,, *A. macrocephalus*.

The Callovien localities were: Scarborough (Yorkshire), Christian Malford (Wilts), Weymouth (Dorset), Lincolnshire, Kelloways (Wilts). European included areas of South-West Germany and France.

[1] *Die Juraformation England*, etc., 1856–8.

Bath Group or Bathonian	Zone of	*Terebratula lagenalis.*
	,,	*T. digona.*

The Bathonian localities embraced Rushden (Northamptonshire), Stanton and Malmsbury (Wilts), Bradford and Hampton Cliff (Wilts).

Bayeux Group or Bajocian	Zone of	*Ammonites Parkinsoni.*
	,,	*A. Humphresianus.*
	,,	*A. Sauzei.*
	,,	*A. Murchisonæ.*
	,,	*Trigonia navis.*
	,,	*Ammonites torulosus.*

The Bajocian localities were: Leckhampton Hill (Gloucestershire), Dundry (Somersetshire), Scarborough and Blue Wyke (Yorkshire), Burton Bradstock (Dorset), Yeovil (Somerset), Frocester (Gloucestershire). European: South-West Germany and France.

Dr. Wright[1] succeeded Oppel in zoning the Inferior Oolite of the South of England and the Yorkshire coast, a work carried out very much upon the same lines, as he adopted the triple zonal subdivisions of that author. Wright's comparisons of these zonal faunas demonstrated a similarity of facies in each area, to prove which he furnished lists of the fossils from the zones of this series of rocks. He insisted upon the importance of specific lists, as it was only by work of this analytical character that the conclusions of the geologist and palæontologist could possibly agree, satisfactory results being only attainable "by accurate observation and a rigorous determination of the specific characters of the fossils imbedded in each superimposed stratum". Each zone was characterized by certain species of Mollusca and other invertebrates, which were special to it, and the author further emphasized the fact that there was an unequal development of the zones not only in England but also in France and Germany. He adopted Oppel's three zonal subdivisions for this series of rocks.

(1) Zone of *Ammonites Parkinsoni*: observed at Leckhampton Hill, Ravensgate Hill, Cold Comfort, Birdlip Hill, Rodborough Hill, Dundry, Bath, Yeovil, and near Bridport.

In the various beds of this zone the following Mollusca were regarded as characteristic:—

Cephalopoda.—*Ammonites Parkinsoni, Martinsi, Truellei, subradiatus.*

Gastropoda.—*Chemnitzia procera.*

Pelecypoda.—*Homomya gibbosa, Ceromya plicata, Trigonia signata, Gryphæa sublobata, Pholadomya Heraulti, Corbicella complanata.*

(2) Zone of *Ammonites Humphresianus*: present at Cleeve Hill, Dundry Hill, Gristhorpe Bay (Yorkshire), Glastonbury Tor, Yeovil, Henbury, Half-way House, Bradford Abbas.

The chief Mollusca distributed through this zone were given as—

Cephalopoda.—*Ammonites Humphresianus, Brocchi, Blagdeni, Braikenridgei, concavus, Dorsetensis, Sowerbyi.*

Gastropoda.—*Chemnitzia Sæmanni; Pleurotomaria ornata, fasciata, punctata; Alaria Phillipsi; Turbo capitaneus.*

[1] Quart. Journ. Geol. Soc., vol. xvi, p. 1, 1860.

Pelecypoda.—*Lima Etheridgei; Pecten barbatus; Ostrea flabelloides, sulcifera, pyxiformis.*

(3) Zone of *Ammonites Murchisonæ*: developed at Leckhampton Hill, Crickley Hill, Beacon Hill, Frocester Hill, Wootton-under-Edge, and the Peak at Robin Hood's Bay (Yorkshire).

This zone exhibited the following leading Mollusca in its various beds:—

Cephalopoda.—*Ammonites Murchisonæ.*

Gastropoda.—*Chemnitzia, Nerinæa.*

Beneath the *Ammonites Murchisonæ* zone occurs the zone of *A. Jurensis*, containing at the top the so-called 'Cephalopoda Bed', with some remaining deposits below, the whole forming the 'Sands'[1] (= Cotteswold Sands, Midford Sands, etc.) which Wright grouped with the Uppermost Lias.

The chief shells of this zone were given as—

Cephalopoda.—*Ammonites opalinus, Jurensis, radians, insignis, variabilis.*

Pelecypoda.—*Trigonia Ramsayi.*

Since Wright's time much zonal work has been accomplished on the British Jurassic rocks by various investigators, although it is only intended in the present observations to notice the leading schemes dealing with this subject. There is, however, an important memoir by Mr. S. S. Buckman[2] which should be referred to, because it illustrates an entirely new feature in the subdivisions of the Jurassic Series. Mr. Buckman divided Jurassic time according to the zoological phenomena of the Ammonite fauna. He recognized two epochs, the Arietidan or earliest, which included the Ammonite families of the Arietidæ and Hildoceratidæ; the later epoch he called Stepheoceratidan, characterized by the families Stepheoceratidæ and Oppelidæ. These two epochs are further subdivided into 'ages', which latter are classified into 'hemeræ', a hemera representing a chronological unit, or in other words indicating the time during which the beds of a zone were deposited.[3] In further explanation of this term it may be interesting to quote a paragraph from Mr. Buckman's[4] memoir "On the Toarcian of Bredon Hill", which shows very definitely the author's own intention as to the meaning and scope of 'hemera'. Speaking of the approximate depths of the Toarcian deposits and their Ammonite hemeræ he remarks—"Taking, therefore, the various maxima of deposits in the South-West of England, it is seen that the work accomplished during the time of the Toarcian stage is represented by a deposition of some 700 feet of strata. The time during which this work was performed is divided

[1] See Dr. Wright's paper "On the Palæontological and Stratigraphical Relations of the so-called 'Sands' of the Inferior Oolite": Quart. Journ. Geol. Soc., vol. xii, p. 292, 1856.

[2] "On the Grouping of some Divisions of so-called 'Jurassic' Time": Quart. Journ. Geol. Soc., vol. liv, pp. 442-69, 1898.

[3] S. S. Buckman, Geological Magazine, 1902, p. 556.

[4] Quart. Journ. Geol. Soc., vol. lix, p. 456, 1903.

into about nine hemeræ, so that the time-value of a hemera, on this evidence, is equal to the time taken to deposit about 80 feet of strata on an average."

Briefly Mr. Buckman's scheme is as follows:—

(A) The Arietidan Epoch represents four ages, viz., Asteroceratan, Deroceratan, Harpoceratan, and Ludwigian.

The Asteroceratan Age includes a part of the Lower Lias, beginning with the zone of *Ammonites Bucklandi* and ending with the *oxynotus* zone. This age is composed of seven hemeræ in ascending order: *rotiformis*, *Gmuendensis*, *Birchi*, *Turneri*, *obtusi*, *stellaris*, and *oxynoti*.

The Deroceratan Age embraces the rest of the Lower Lias and nearly all the Middle Lias, and includes seven hemeræ: *raricostati*, *armati*, *Jamesoni*, *Valdani*, *striati*, *margaritati*, and *spinati*.

The Harpoceratan Age includes a small part of the Middle Lias and the whole of the Upper Lias; it contains ten hemeræ: *acuti*, *falciferi*, *bifrontis*, *lilliæ*, *variabilis*, *striatuli*, *Struckmanni*, *dispansi*, *Dumortieriæ*, *Moorei*.

The Ludwigian Age includes part of the Yeovil Sands and part of the Inferior Oolite; it comprises six hemeræ: *Aalensis*, *opaliniformis*, *Scissi*, *Murchisonæ*, *Bradfordensis*, *concavi*.

(B) The Stepheoceratidan Epoch consists of two ages—Sonninian or oldest and Parkinsonian or latest. These are again subdivided into hemeræ. This epoch extends from the lower division of the Inferior Oolite to the Cornbrash of the Bathonian Series.

The Sonninian Age constitutes five hemeræ: *discitæ*, *Sonniniæ*, *Witchelliæ*, *Sauzei*, *Blagdeni*.

In the Parkinsonian Age is represented the following hemeræ: *Niortensis*, *garantianæ*, *Truelli*, *zigzag*, *fuscæ*, *subcontracti*, (maxillata), (coarctatæ), *disci*.

Complicated as Mr. Buckman's system appears, there is no doubt as to its uniqueness of detail and its far-reaching consequences, both to the geologist and the palæoconchologist. To the former it is expected to serve as a 'geological calendar', so that collectors may be able to date the species they find, whilst to the latter it is intended as an assistance in biological research, and so to advance the study of evolution. Its methods will, doubtless, have to be considered in all future classifications connected, at any rate, with the history of Jurassic rocks. The 'hemeræ' have already been adopted, and especially is this the case in Mr. L. Richardson's memoirs [1] on the "Liassic Dentaliidæ", "The Inferior Oolite, etc., of the Bath–Doulting District",[2] and "The Inferior Oolite, etc., between Rissington and Burford".[3]

We will now consider the zones of the Cretaceous period, in which molluscan remains have played an important part. Taking its lower portion first, we have to recognize the analytical researches of Professor Judd, C.B.,[4] in connection with his memoir of 1868 "On the Speeton Clay", the term 'Speeton Clay' having been founded

[1] Quart. Journ. Geol. Soc., vol. lxii, pp. 573–96, pl. xlv, 1906.
[2] Ibid., vol. lxiii, pp. 383–436, 1907.
[3] Ibid., vol. lxiii, pp. 437–44, 1907.
[4] Ibid., vol. xxiv, p. 218, 1868.

by John Phillips[1] during 1829 for a series of beds on the Yorkshire coast ranging from the Kimeridge Clay to the Gault. In descending order Professor Judd identified as Neocomian the following beds in the Speeton Cliff, a result mainly arrived at from a study of the Ammonites, although other molluscan species were adopted in addition for discriminating his zonal subdivisions :—

Age of Deposits.	Characteristic Mollusca.
Upper Neocomian (clays and cement beds; 150 feet).	Cephalopoda : *Belemnites semicanaliculatus*, *Ammonites Deshayesi*, *Ancyloceras*(?) *grandis*. Pelecypoda: *Perna Mulleti ; Exogyra sinuata ; Pecten elongata*, *orbicularis ; Thetis Sowerbyi ; Panopœa plicata*, *neocomiensis*.
Middle Neocomian (including zone of *Pecten cinctus* and *Ancyloceras* beds; 150 feet).	Cephalopoda: *Belemnites jaculum ; Ammonites ; Ancyloceras Duvali*, *Emerici*. Pelecypoda : *Pecten cinctus*, *Exogyra sinuata*.
Lower Neocomian (containing zones of *Ammonites Speetonensis*, *A. noricus*, and *A. astierianus* ; 200 feet).	Cephalopoda: *Ammonites Speetonensis*, *rotula*, *nisus*, *noricus*, *marginatus*, *astierianus*, *multiplicatus*, *hystrix ; Belemnites jaculum*, *lateralis ; Ancyloceras Puzosianum*, *Duvali*, *Emerici*. Gastropoda : *Cerithium* sp., *Trochus* sp. Pelecypoda : *Exogyra subsinuata*, *subplicata ; Thracia Phillipsi ; Pholadomya* sp. ; *Pholas constricta*.

Then follow the Jurassic beds of Portlandian, Kimeridgian, etc.

In a subsequent paper Professor Judd[2] showed that the Speeton Cliff beds furnished a key to the interpretation of many isolated deposits of similar age distributed over various districts of Northern Europe. On that occasion he introduced Orbigny's stratigraphical terms, and bracketed *Aptien* with his Upper Neocomian, *Urgonien* with Middle Neocomian, and *Neocomien* with Lower Neocomian.

Twenty years later Mr. Lamplugh's[3] investigations "On the Subdivisions of the Speeton Clay" were published, the Belemnites forming the basis of classification. The term 'Middle Neocomian' used by Judd was thought to be unnecessary, since the beds which had received that name exhibited a 'Lower Neocomian' fauna, both above and below. Judd's zone of *Ammonites astierianus* was abolished in favour of the zone of *Belemnites lateralis*, which comprised a fauna showing marked Jurassic affinities, and comparable with that of the 'Upper Volga' Beds of Southern Russia, as described by Professors Pavlov[4] and Nikitin.[5] Lamplugh therefore regarded the zone of

[1] *Geology of Yorkshire*, 1829, p. 76.
[2] Quart. Journ. Geol. Soc., vol. xxvi, p. 326, 1870.
[3] Ibid., vol. xlv, p. 575, 1889.
[4] "Jurassique supérieur et Crétacé inférieur de la Russie et de l'Angleterre," 1889.
[5] "Quelques excursions dans les Musés et dans les terrains Mésozoiques de l'Europe occidentale, et comparaison de leur faune avec celle de la Russie" : Bull. Soc. Belge Géol., vol. iii, pp. 29–58, 1889.

Belemnites lateralis as representing passage beds from Jurassic to Lower Cretaceous or Neocomian.

The zonal subdivisions and their Mollusca were as follows:—

Age of Deposits.	Characteristic Mollusca.
[Albian.] Marls forming Zone of *Belemnites minimus* (= uppermost beds of the Speeton Clay and with affinities to the 'Red Chalk').	Cephalopoda: *Belemnites minimus, attenuatus, ultimus.* Pelecypoda: *Inoceramus concentricus, sulcatus* var. (?); *Ostrea* sp.; *Avicula Rauliniana* (?); *Nucula pectinata* (?).
[Aptian.] Zone of *Belemnites semicanaliculatus* (?) (= *Belemnites Brunsvicensis* of Strombeck, according to Judd, see p. 611 of Lamplugh's paper).	Cephalopoda: *Belemnites semicanaliculatus* (?), *jaculum; Ammonites Deshayesi, nucleus; Crioceras; Ancyloceras.* Gastropoda: *Rostellaria Phillipsi, candidula, bicarinata.* Pelecypoda: *Exogyra sinuata, Pecten orbicularis, Pinna tetragona, Cucullæa securis, Nucula impressa, Panopæa neocomiensis, Pholadomya Martini.*
Neocomian (Zone of *Belemnites jaculum*).	Cephalopoda: *Belemnites jaculum, semicanaliculatus; Crioceras* (*Ancyloceras*); *Crioceras Duvali, puzosianum; Ammonites marginatus, Speetonensis, astierianus, nucleus, rotula, noricus.* Gastropoda: *Pleurotomaria* sp.; *Trochus pulcherrimus, Cerithium aculeatum.* Pelecypoda: *Exogyra sinuata, Pecten cinctus, Isocardia angulata, Inoceramus venustulus, Thracia Phillipsi.*
Zone of *Belemnites lateralis.* (In this zone the author found the 'Portlandian beds' of Leckenby,[1] the fossils showing marked Jurassic affinities.)	Cephalopoda: *Belemnites lateralis; Ammonites noricus, Gravesianus.* Pelecypoda: *Avicula inæquivalvis; Pecten lens* var. *Morini, cinctus; Exogyra sinuata* var.; *Astarte senecta; Nucula* sp.

Professor A. Pavlov and Mr. Lamplugh[2] contributed a joint memoir in 1892 on the "Argiles de Speeton et leurs équivalents", and subdivided the beds according to Belemnite characters as originally proposed by Mr. Lamplugh, in which the following zones and their characteristic Mollusca were given as—

Albian (zone of *Belemnites minimus*). Cephalopoda: *Belemnites minimus, attenuatus, ultimus.* Pelecypoda: *Inoceramus concentricus, Nucula pectinata.*

[1] "Note on the Speeton Clay of Yorkshire" (Geologist, 1859, p. 9), and in Dr. Wright's *British Fossil Cretaceous Echinodermata* (Mon. Pal. Soc., 1864, p. 9).

[2] Bull. Soc. Imp. Nat. Moscou, Nos. 3, 4, pls. iv–viii, xiii–xviii, pp. 181–276, 445–570, 1891.

Aptian (zone of *Belemnites Brunsviciensis*). Cephalopoda: *Belemnites Brunsviciensis, Jasikowi, obtusirostris; Crioceras.* Gastropoda: *Rostellaria Parkinsoni.* Pelecypoda: *Cucullæa securis, Isocardia angulata, Nucula subangulata, Exogyra.*

Neocomian (zone of *Belemnites jaculum*). Cephalopoda: *Belemnites jaculum, Jasikowi, cristatus, subquadratus; Olcostephanus umbonatus, Decheni, discofalcatus, progrediens, Spectonensis, concinnus, Payeri, inversus, subinversus, versicolor, Astieri, sulcosus; Crioceras; Ancyloceras Matheroni; Holcodiscus rotula; Hoplites regalis, amblygonius, Vaceki, munitus.* Gastropoda: *Rostellaria; Trochus pulcherrimus.* Pelecypoda: *Inoceramus venustulus; Pecten Morini, cinctus.*

Transitional Beds between Neocomian and Uppermost Jurassic (zone of *Belemnites lateralis*). Cephalopoda: *Belemnites lateralis, subquadratus, explanatus, Russiensis; Olcostephanus bidichotomus* cf. *Gravesi, Keyserlingi, Lamplughi, fragilis; Hoplites amblygonus, hystrix, munitus.* Pelecypoda: *Pecten cinctus; Exogyra sinuata; Astarte senecta.* Coprolite Bed — Cephalopoda: *Perisphinctes Panderi, Tchernyschovi, scythicus, dorsoplanus.*

Upper Kimeridge. Cephalopoda: *Belemnites magnificus; Perisphinctes virgatus, Pallasi.* Pelecypoda: *Lucina minuscula, Ostrea gibbosa.*

The Gault deposits of the Cretaceous Series have long been studied by various investigators, their development being mostly known in South of England localities, and prominently in the neighbourhood of Folkestone (Copt Point and Eastwear Bay). To the late Mr. De Rance [1] is due the credit for having first attempted their systematic zoning at Folkestone, Ammonite species being mainly used as the index-fossils of the zones. He recognized the Continental term 'Albian' for this series of deposits, and subdivided them into eleven zones, which were grouped as 'Upper' and 'Lower Albian'. The zones with a few of their characteristic Mollusca were listed as follows:—

Upper Albian (zone of *Ammonites Goodhalli* and *A. rostratus*). Cephalopoda: *Ammonites Goodhalli; Belemnites ultimus.* Pelecypoda: *Pecten orbicularis.* (Zone of *Ammonites circularis* and *Kingena lima.*) Cephalopoda: *Ammonites cristatus, varicosus; Belemnites (minimus) ultimus; Hamites armatus, attenuatus.* Pelecypoda: *Nucula ovata, bivirgata; Pecten asper.* (Zone of *Nautilus Deslongchampsianus.*)

Lower Albian (zone of *Ammonites Beudanti*). Cephalopoda: *Ammonites versicostatus.* Gastropoda: *Rostellaria* allied to *pyrenaica; Pleurotomaria Gibbsi.* (Zone of *Ammonites auritus.*) Cephalopoda: *Hamites simplex.* Gastropoda: *Acteon affinis; Avellana inflata; Rostellaria Robinaldina, carinella, cingulata; Acmæa tenuicosta; Turbo* allied to *Yonninus.* Pelecypoda: *Pecten quinquecostatus.* (Zone of *Ammonites denarius.*) (Zone of *Nautilus Clementinus.*) Cephalopoda: *Hamites tuberculatus,*

[1] Geological Magazine, p. 163, 1868.

Sablieri. Gastropoda : *Rostellaria varicosa; Bellerophina minuta.* Pelecypoda : *Gervillia solenoides.* (Zone of Crustacea—*Palæocorystes.*) Gastropoda : *Turbo decussatus; Ampullaria lævigata.* Pelecypoda : *Pinna tetragona.* (Zone of *Ammonites auritus*, var.) Gastropoda : *Fusus iterianus, Scalaria Dupiniana.* Pelecypoda : *Mytilus Galliennei.* (Zone of *Ammonites Benettianus* ?) The organic remains are said to be few in this zone. (Zone of *Ammonites interruptus.*) Cephalopoda : *Ammonites Deshayesi, dentatus*, and *Gervillianus.* The zone of *Ammonites mammillaris* at the base was regarded as belonging to the Aptian stage of the Cretaceous formation.

A few years afterwards the late Hilton Price [1] published his researches on the Folkestone Gault, based mainly on De Rance's work of 1868 ; in fact, with only trifling emendations he adopted the zonal classification of the beds as first suggested by that author. His work may be tabulated as follows, the characteristic Mollusca of each zone, mentioned by the author, being also included :—

Upper Gault (about 72 feet). (Zone of *Ammonites rostratus.*) Cephalopoda : *Ammonites Goodhalli, rostratus, varians.* Pelecypoda : *Inoceramus Crippsi; Pecten Raulinianus.* (Zone of *Kingena lima.*) Cephalopoda : *Ammonites rostratus.* Pelecypoda : *Plicatula pectinoides.* Brachiopoda : *Kingena lima.* (Zone of *Ammonites varicosus.*) Cephalopoda : *Ammonites varicosus, rostratus.* Pelecypoda : *Inoceramus sulcatus, subsulcatus.*

Junction Bed (zone of *Ammonites cristatus*). Cephalopoda : *Ammonites Beudanti, cristatus.* Pelecypoda : *Pholas Sanctæcrucis; Mytilus Galliennei; Cucullæa glabra; Cyprina quadrata.*

Lower Gault (about 28 feet). (Zone of *Ammonites auritus.*) Gastropoda : *Pteroceras bicarinatum ; Fusus indecisus ; Aporrhais Parkinsoni.* Pelecypoda : *Nucula bivirgata, ornatissima.* (Zone of *Ammonites denarius.*) Cephalopoda : *Ammonites cornutus, denarius ; Turrilites Lugardianus.* (Zone of *Ammonites lautus.*) Cephalopoda : *Ammonites lautus.* Gastropoda : *Solarium moniliferum ; Phasianella ervyna.* (Zone of *Ammonites Delaruei.*) Cephalopoda : *Ammonites Delaruei.* Gastropoda : *Natica obliqua ; Fusus gaultinus ; Avellana pulchella.* (Zone of Crustacea—*Palæocorystes.*) Cephalopoda : *Hamites attenuatus.* Pelecypoda : *Leda* allied to *solea ; Pinna tetragona.* (Zone of *Ammonites auritus*, var.) Cephalopoda : *Ammonites auritus*, var. Gastropoda : *Cerithium trimonile ; Fusus itierianus ; Aporrhais calcarata.* Pelecypoda : *Lucina tenera ; Corbula gaultina ; Arca nana ; Nucula pectinata.* (Zone of *Ammonites interruptus.*) Cephalopoda : *Ammonites interruptus ; Crioceras astierianum ; Hamites rotundus.*

At the base was recognized the zone of *Ammonites mammillaris* and regarded as belonging to the Lower Greensand or Upper Neocomian.

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[1] Quart. Journ. Geol. Soc., vol. xxx, p. 342, 1874, and a separately published work on *The Gault*, 1879.

Dr. Barrois,[1] writing upon the age of the 'Folkestone Beds', identified the zone of *Ammonites mammillaris* as synchronous with that of the Paris Basin, which he regarded as belonging to the Gault, and therefore classed the English representative in the same formation.

The present writer in 1896[2] identified the zones of *Acanthoceras mammillatum* and *Hoplites interruptus* at Okeford Fitzpaine, in Dorsetshire, the former being regarded as the oldest and representing the base of the Albian (= Gault) deposits, and the latter as immediately succeeding it. A number of shells were described as being associated with the zonal forms.

The zone of *Hoplites interruptus* contained—

Cephalopoda: *Hoplites splendens; Nautilus Clementinus.* Gastropoda: *Actæonina formosa; Anchura carinata; Ringinella inflata; Natica gaultina; Scala Dupiniana; Solarium subornatum.* Pelecypoda: *Cucullæa carinata; Syncyclonema orbicularis; Gervillia Forbesiana; Inoceramus concentricus; Lima parallela; Mytilus subsimplex; Nucula pectinata; Exogyra canaliculata; Pecten Galliennei; Pleuromya plicata; Pholadomya favrina* (?); *Solen Dupinianus; Trigonia aliformis, archiaciana, Fittoni.*

The above Mollusca contained species occurring in similarly aged deposits at Folkestone, Black Ven, Cambridge, Blackdown, and Hunstanton (= Red Chalk beds), as well as in Continental localities.

The zone of *Acanthoceras mammillatum* contained the following shells associated with the index-form:—

Cephalopoda: *Hoplites Benettianus.* Pelecypoda: *Pleuromya plicata; Cucullæa carinata; Ostrea Leymeriei; Exogyra sinuata.*

This zone has been recognized at Sandgate, Folkestone, Crockerton, etc., and further localities in France, Switzerland, etc.

It may be here mentioned that an analogous fauna to that characterizing the ordinary Gault deposits of this country is found in the Blackdown[3] and Haldon Beds of Devonshire, in the phosphatic 'Greensand' of Cambridge,[4] and in the so-called 'Red Chalk' of Norfolk,[5] etc. (Hunstanton, etc.). Hence the whole of these strata are now generally included in the Albian stage of the Cretaceous Series.

The Chalk formation has always offered a fascinating field for study because of the many varieties of its organic remains and their unusually good preservation, causes which have contributed very largely to the exact and interesting zoning work which has been accomplished both by English and Continental palæontologists. In the different schemes that have been published from time to time on this subject, it is noticeable that the index-fossil is not so frequently

[1] Ann. Soc. Géol. Nord, vol. iii, pp. 23–5, 1876.

[2] R. B. Newton in Geological Magazine, 1896, p. 198; and Proc. Dorset Nat. Hist. Antiq. Field Club, vol. xviii, pp. 66–99, pls. i–iii, 1897.

[3] W. Downes, Quart. Journ. Geol. Soc., vol. xxxviii, p. 75, 1882.

[4] Jukes-Browne, ibid., vol. xxxi, p. 256, 1875; vol. xxxiii, p. 485, 1877.

[5] H. G. Seeley, Ann. Mag. Nat. Hist., ser. III, vol. vii, p. 233, 1861; T. Wiltshire, Quart. Journ. Geol. Soc., vol. xx, p. 327, 1864; Proc. Geol. Assoc. (separately published), 1859, pp. 1–18, pls. i–iv; and Quart. Journ. Geol. Soc., vol. xxv, p. 185, 1869.

withdrawn from the molluscan group as was done among the older zones of the Mesozoic rocks, from the fact that other organisms, and chiefly the Echinoids, occur much more abundantly than shells, and, moreover, are considered to possess characters which better adapt them for the subdividing of the beds.

In 1870 Caleb Evans[1] published the results of a study he had made of the Chalk sections between Croydon and Oxtead in Surrey. He found that the Chalk deposits of that area were divisible into zones, similar to those which had been recognized in Northern France by Hébert,[2] in North-West Germany by Von Strombeck,[3] in Saxony and Bohemia by Schloenbach,[4] and in Western France by Triger.[5] He therefore concluded that the whole of these so-called 'Chalk' beds were formed in one hydrographical area. He pointed out also that the Pelecypod shell variously quoted as *Inoceramus mytiloides*, *labiatus*, or *problematicus* was an abundant organism of the second oldest zone of his scheme, and as commonly found in Continental areas as in this country. The index-fossils used for discriminating the zones are a combination of forms withdrawn from the Mollusca and Echinodermata. The zones were as follows:—

Zone with *Micraster coranguinum* in the upper part and *Inoceramus Cuvieri* below. = Chalk with bands of flints.

Zone with *Micraster coranguinum* in the upper part and *Ananchytes ovata* and *Spondylus spinosus* below. = Chalk with bands of flints.

Zone with *Holaster planus* and *Micraster corbovis*. = Lowest beds of Chalk with bands of flint nodules.

Zone with *Inoceramus Brongniarti* and *Galerites albogalerus*, var. *subrotundus*. = White Chalk with few flints.

Zone of *Ammonites peramplus* and *Inoceramus mytiloides*. = White Chalk without flints.

Zone of *Ammonites varians* and *Belemnitella plena*. = Chalk Marl and Grey Chalk.

Writing on the "Ammonite Zones in the Isle of Thanet" during 1874, F. A. Bedwell[6] acknowledged that Ammonites marked definite beds or "zones of life" as he expressed it. He regarded it as necessary for accurate palæontological work that collectors should obtain their fossils from properly detailed sections where separate deposits could be searched rather than from indiscriminate positions in the cliffs. The total thickness of the Chalk in the Isle of Thanet was given as 180 feet, and in this the author marked the occurrence of eighty-nine large Ammonites with an average diameter of 3 feet,

[1] "On some Sections of Chalk between Croydon and Oxtead": Geol. Assoc., 1870, pp. 1–40 (separately published).

[2] Bull. Soc. Géol. France, ser. II, vol. xiv, p. 731, 1857; vol. xvi, p. 143, 1858; vol. xx, p. 605, 1863, etc.

[3] Zeitsch. deutsch. geol. Ges., vol. xv, p. 97, 1863.

[4] Palæontographica, vol. xiii, p. 267, 1866.

[5] Echinoides Dép. Sarthe (Cotteau & Triger), 1855–69 (Zoologique et stratigraphique).

[6] Proc. Geol. Assoc., vol. iii, p. 217, 1874; Geological Magazine, 1874, pp. 16, 94.

several of them being referred to *A. leptophyllus*, whilst a few were determined as *A. Lewesiensis* and one example as *A. peramplus*, all of which, it was suggested, might represent one species. The lithological features of the subject, in connection with the occurrence of a line of scattered flints, were of great importance, so much so that in more recent years Dr. Arthur Rowe[1] named it the 'Bedwell-line', regarding it as representing a zoological break in the zone of *Marsupites testudinarius*, above which, speaking generally, the Cephalopod *Actinocamax Merceyi* is always found, whilst *Ammonites leptophyllus* was restricted to a position below the line.

Mr. C. J. A. Meyer[2] contributed an important memoir in 1874 on the Cretaceous rocks of Beer Head in Devonshire. The Chalk cliffs of this area form the most westerly Chalk promontory of England. A general vertical section was given of the district, subdivided into twenty beds representing formations ranging from the Gault to the Upper Chalk, the Blackdown Beds being bracketed with the Gault, and the Warminster deposits regarded as equivalent to the Chloritic Marl. The whole of the beds were classified into what the author termed 'zones of fossils', the indices of which were mainly molluscan, belonging to the Cephalopoda and Pelecypoda, the remaining index-fossils being species of Echinoids, Brachiopoda, and Foraminifera. These zones were thus enumerated:—

Formations.	Zones of Fossils.
Upper (?) Chalk . . .	*Micraster coranguinum.*
Middle Chalk . . .	*Terebratula carnea.*
	Inoceramus Cuvieri.
	Terebratula semiglobosa.
Lower Chalk . . .	*Inoceramus Brongniarti.*
	Holaster planus.
	Inoceramus mytiloides.
	Micraster corbovis.
	Rhynchonella Cuvieri.
Chalk Marl	*Discoidea subuculus.*
	Ammonites Mantelli.
	Discoidea cylindrica.
	Rhynchonella Mantelliana.
Chloritic Marl . . .	*Ammonites Rhotomagensis*
(Warminster Beds.)	*Scaphites æqualis.*
	Holaster subglobosus.
	Catopygus carinatus.
	Rhynchonella dimidiata.
	Terebratula pectita.
	Exogyra columba (var.).
	Siphonia.
	Nautilus lærigatus.
	Discoidea subuculus.

[1] Proc. Geol. Assoc., vol. xvi, p. 295, 1900.
[2] Quart. Journ. Geol. Soc., vol. xxx, pp. 369–93, 1874.

Formations.	Zones of Fossils.
Upper Greensand . .	*Orbitolina concava.*
	Exogyra digitata.
	E. columba.
	Janira quadricostata.
	Pecten orbicularis.
	Exogyra conica.
	E. lævigata.
Gault	*Inoceramus sulcatus.*
(Blackdown Beds.)	*Exogyra conica* (small var.).

The classic memoir of Dr. Charles Barrois[1] on the Upper Cretaceous deposits of England and Ireland appeared in 1876. This author was of opinion that previous descriptions of the Chalk deposits of Great Britain were somewhat inadequate, and he therefore submitted a detailed account of the distribution of the beds observed in the various areas of the South of England, Norfolk, Lincolnshire, Yorkshire, and Northern Ireland. He utilized zonal subdivisions, adopting those proposed by Hébert[2] in his scheme of the Cretaceous deposits of the Paris Basin region of France. The faunas were also compared with those of North-West Germany; whilst the Irish Chalk he regarded as belonging to zones included in the Cenomanian, Turonian, and Senonian horizons of the Upper Cretaceous; and so resembling in this way similarly aged deposits of England.

The zones adopted by Barrois were based on five Echinoderms, one Brachiopod, and five had their index-fossils selected from the molluscan group of organisms.

Senonian	Zone of *Belemnitella mucronata.*
	,, *Marsupites ornatus.*
	,, *Micraster coranguinum.*
	,, *M. cortestudinarium.*
Turonian	,, *Holaster planus.*
	,, *Terebratulina gracilis.*
	,, *Inoceramus labiatus.*
Cenomanian	,, *Belemnites plenus.*
	,, *Holaster subglobosus.*
	Chloritic Marl.
	Zone of *Pecten asper.*
	,, *Ammonites inflatus.*

An excellent piece of zoning work was accomplished by Mr. Henry Woods[3] some years since in connexion with the Mollusca of the 'Chalk Rock', which was a deposit so named by Mr. Whitaker,[4] who

[1] "Recherches sur le Terrain Crétacé supérieur de l'Angleterre et de l'Irlande": Mém. Soc. géol. Nord [Lille], 1876, pp. 234, maps and sections. Ann. Soc. géol. Nord [Lille], vol. iii, p. 190, 1876.

[2] Bull. Soc. géol. France, published mostly in the seventies.

[3] Quart. Journ. Geol. Soc., vol. lii, pls. ii–iv, pp. 68–98, 1896; vol. liii, pls. xxvii–xxviii, pp. 377–404, 1897.

[4] *Catalogue of Rock-specimens in the Museum of Practical Geology*, 2nd ed., p. 296, 1860; Quart. Journ. Geol. Soc., vol. xvii, p. 166, 1861.

considered it to be the topmost bed of the Lower Chalk. Mr. Woods, however, regarded it as occurring at the top of the Middle Chalk, that is, succeeding the zone of *Holaster planus* and followed by the zone of *Micraster cortestudinarium*. The Chalk Rock fauna was recognized as being distributed over Berkshire, Oxfordshire, Buckinghamshire, Wiltshire, Hertfordshire, Kent, Cambridgeshire, and Hampshire, being known also on the Continent—France, Germany, etc. As in North-Western Germany (Westphalia, etc.), this Chalk bed represents the zone of *Heteroceras Reussianum*, so Mr. Woods suggested the adoption of that name for the zone of the 'Chalk Rock' as it occurs in this country. The Mollusca described and figured in this work comprised Cephalopoda, Gastropoda, Scaphopoda, and Pelecypoda. Instructive tables were given showing the distribution of the species throughout the various zones of England, Ireland, and European areas. The author considered that the fauna presented a Turonian facies, and he also regarded it as of a comparatively shallow-water character.

In 1889 Mr. Jukes-Browne[1] formulated a zonal scheme for the British Chalk formation, which resembled that of Barrois in its main divisions, although fewer Mollusca were used for the index-fossils—

Upper Chalk	Zone of *Marsupites*. ,, *Micraster coranguinum*. ,, *M. cortestudinarium*.
	Chalk Rock.
Middle Chalk	Zone of *Holaster planus*. ,, *Terebratulina gracilis*. ,, *Rhynchonella Cuvieri*.
	Melbourn Rock at base.
Lower Chalk	Zone of *Belemnitella plena*. ,, *Holaster subglobosus*, with Totternhoe Stone at base. ,, *Ammonites varians*.

Another scheme was proposed by Mr. Jukes-Browne[2] in 1903 for subdividing the Lower and Middle Chalk of England into zones, which differed from that of 1889, as each division was formed of two zones instead of three. These, with their characteristic Mollusca, were as follows:—

Middle Chalk (zone of *Terebratulina gracilis*, var. *lata*). Cephalopoda: *Prionotropis Woolgari; Pachydiscus peramplus; Haploceras peramplus*. Pelecypoda: *Inoceramus Cuvieri; Spondylus spinosus*. (Zone of *Rhynchonella Cuvieri*.) Cephalopoda: *Acanthoceras nodosoides*. Pelecypoda: *Inoceramus mytiloides*.

Lower Chalk (zone of *Holaster subglobosus*). Cephalopoda: *Acanthoceras navicularis, rotomagensis; Haploceras Austeni; Actinocamax plenus*. (Zone of *Ammonites varians*.) Cephalopoda:

[1] In W. Whitaker's *The Geology of London* (Mem. Geol. Surv. England and Wales), vol. i, p. 58, 1889.

[2] *Cretaceous Rocks of Britain: The Lower and Middle Chalk of England* (Mem. Geol. Surv. United Kingdom), 1903, p. 558.

Schlœnbachia varians; Acanthoceras Mantelli, rotomagensis; Scaphites æqualis. Pelecypoda: *Inoceramus latus; Aucellina gryphæoides.*

The British Upper Chalk beds were finally classified for the Geological Survey by Mr. Jukes-Browne[1] in 1904, in which the zone of *Holaster planus* was recognized as the base, which differed from his views of 1889, when it was regarded as the topmost zone of the Middle Chalk (or Turonian), this latter being the position generally acknowledged by all authorities on the Chalk zones.

A new zone was established on this occasion for the Chalk deposits near Trimingham and Mundesley on the Norfolk coast, regarded as the highest Chalk of England, which was termed the zone of *Ostrea lunata*, its position being just above the *Belemnitella mucronata* zone. The new scheme of zones was as follows:—

Zones.	Characteristic Mollusca.
Ostrea lunata	Pelecypoda: *Ostrea lunata; Pecten serratus.*
Belemnitella mucronata . .	Cephalopoda: *Belemnitella mucronata, lanceolata.*
Actinocamax quadratus . .	Cephalopoda: *Actinocamax quadratus, Belemnitella lanceolata.*
Marsupites testudinarius . .	Cephalopoda: *Ammonites leptophyllus; Actinocamax verus, granulatus.*
Micraster coranguinum . .	Cephalopoda: *Actinocamax verus.* Pelecypoda: *Inoceramus involutus.*
Micraster cortestudinarium .	[No characteristic Mollusca are given.]
Holaster planus	Cephalopoda: *Heteroceras Reussianum; Scaphites Geinitzi; Pachydiscus peramplus.* Gastropoda: *Trochus Schlüteri; Solariella gemmata.*

Following this, it is important to mention that Mr. R. M. Brydone,[2] who had studied the Trimingham Chalk of Norfolk, published, in 1906, his observations on this subject. He objected to the "zone of *Ostrea lunata*", established by Mr. Jukes-Browne for the Chalk beds of this locality above the *Belemnitella mucronata* zone, because that fossil, although abundantly represented, did not occur throughout the whole of the zone; he therefore suggested naming it "the zone of *Terebratulina gracilis* and *T. Gisei*", as those forms of Brachiopods were found in[3] all its beds. In a subsequent paper on the same subject Mr. Brydone again called in question the zone of *Ostrea lunata*, and apparently forgetting that two years previously he had suggested another zonal name to take its place, stated that "hence the zone of Chalk at Trimingham, lying above the zone of *Belemnitella mucronata*, now divided and defined by me for the first time, requires a name".

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[1] *Cretaceous Rocks of Britain: The Upper Chalk* (Mem. Geol. Surv. United Kingdom), 1904, p. 5.

[2] Geological Magazine, 1906, p. 15.

[3] Quart. Journ. Geol. Soc., vol. lxiv, p. 410, 1908.

The latest and most exhaustive researches on the British Chalk are undoubtedly those made by Dr. Arthur W. Rowe[1] in a series of memoirs on "The Zones of the White Chalk of the English Coast", published between 1900 and 1908, the maps to which were constructed by Mr. C. Davies Sherborn. From long and careful collecting, the author plans out the zonal distribution of fossils in the coastal white chalk deposits of England, as observed in Kent, Sussex, the Isle of Wight, Dorset, Devonshire, and Yorkshire.

He divided these deposits into seven zones, but the only mollusc used as an index-fossil was that of the Cephalopod *Actinocamax quadratus*, which is regarded as characterizing the latest or newest zone of the series, the remainder being Echinoderms and Brachiopods. The distribution of the various species of the Mollusca is, however, most minutely treated, and by a system of tables the zonal position of any form can be immediately ascertained, this same remark applying to the other members of the invertebrate groups of zoology.

The arrangement of these zones and their characteristic Mollusca are given as follows:—

Senonian (zone of *Actinocamax quadratus*). Cephalopoda: *Actinocamax quadratus, granulatus* (*Merceyi*); *Hamites; Scaphites inflatus.* Pelecypoda: *Inoceramus lingua; Ostrea Wegmanniana; Avicula tenuicostata.* (Zone of *Marsupites testudinarius.*) Cephalopoda: *Actinocamax granulatus, verus; Ammonites leptophyllus.* Pelecypoda: *Ostrea vesicularis, Wegmanniana.* (Zone of *Micraster coranguinum.*) Cephalopoda: *Actinocamax granulatus, westfalicus.* Pelecypoda: *Inoceramus Cuvieri, involutus.* (Zone of *Micraster cortestudinarium.*) Pelecypoda: *Plicatula Barroisi; Inoceramus Lamarcki.*

Turonian (zone of *Holaster planus*). Gastropoda: *Pleurotomaria perspectiva; Turbo gemmatus.* Pelecypoda: *Inoceramus Lamarcki, Brongniarti; Plicatula Barroisi; Ostrea proboscidea.* (Zone of *Terebratulina gracilis.*) Cephalopoda: *Ammonites peramplus.* Pelecypoda: *Inoceramus labiatus, Brongniarti, Lamarcki; Spondylus spinosus; Ostrea vesicularis.* (Zone of *Rhynchonella Cuvieri.*) Cephalopoda: *Ammonites Cunningtoni, peramplus.* Pelecypoda: *Inoceramus labiatus, Lamarcki; Ostrea vesicularis.*

In concluding my *résumé* of the geological zones it is almost needless to remark that due attention to such a subject is a necessary adjunct to accuracy of collecting, and all studies in this direction must lead to satisfactory results. No longer is the palæontologist contented with acquiring his specimens indiscriminately from a quarry or a section, but he is careful to obtain them from each separate bed, so that he may become acquainted with individual faunas, the organisms of which will often present interesting points of variation and change, and so form the basis of inquiries connected with the evolution of genera and species.

[1] Proc. Geol. Assoc., vol. xvi, pp. 289–368 (Kent and Sussex), 1900; vol. xvii, pp. 1–76 (Dorset), 1901; vol. xviii, pp. 1–51 (Devon), 1903; vol. xviii, pp. 193–296 (Yorkshire), 1904; vol. xx, pp. 209–352 (Isle of Wight), 1908.

It is among the Mesozoic rocks that zonal work has been so largely and successfully accomplished; and speaking of quite modern years there is no doubt that the investigations of Mr. S. S. Buckman on the Jurassics and of Dr. Rowe on the Upper Cretaceous have done much to direct attention to the great value of this form of research, besides inspiring the collector with a greater zeal for his field-work. Since the publication of Dr. Rowe's first memoir on the Coastal Upper Chalk of this country in 1900, a number of observers have shown their interest in certain local developments of the Chalk and their zones, and the issue of many important papers has been the direct result; although such works are not referred to on this occasion they are of great value as forming part of the history of zonal geology.